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(54) HARNESS DESIGN APPARATUS

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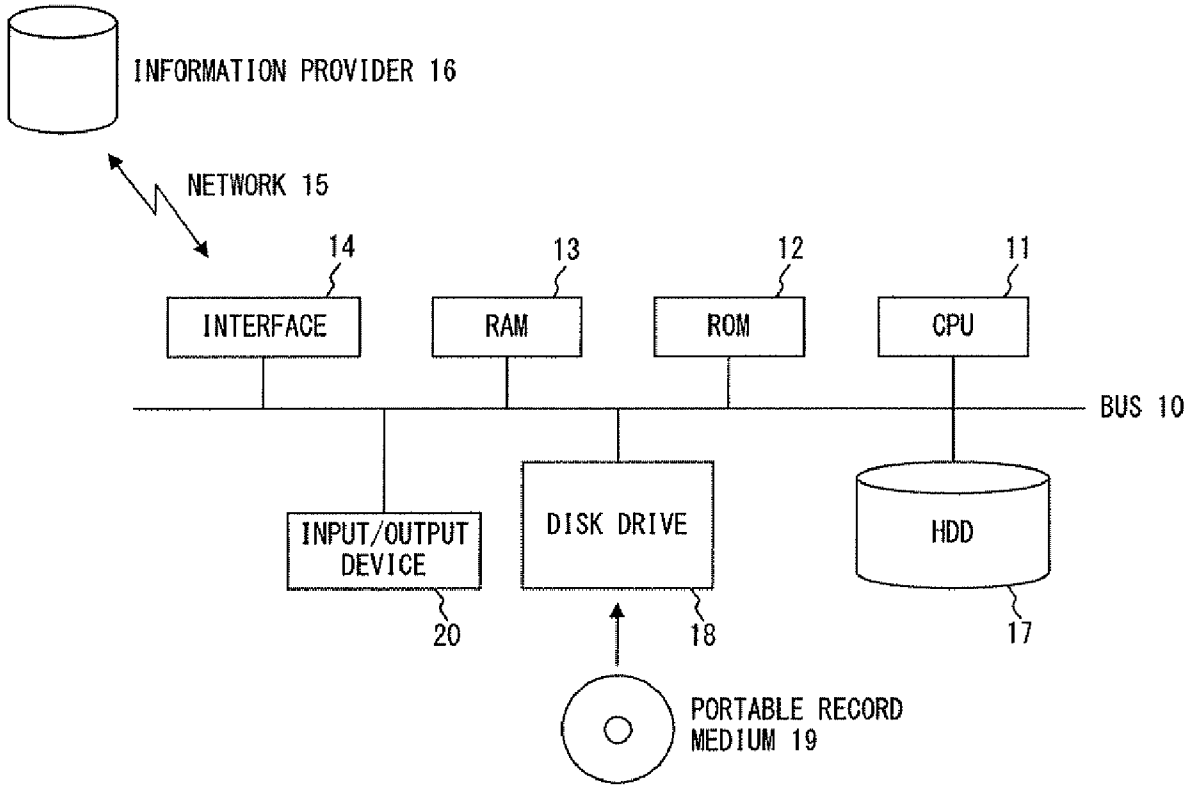
(57) **ABSTRACT**

First, the position and the length of a harness are set. Next, a shape setting function having an unknown variable that minimizes potential energy as a binding position is generated, and a position of the minimum potential energy at a bending position is calculated in the Lagrange Multiplier Method. The position of the minimum potential energy obtained by the Lagrange Multiplier Method is the optimum binding position.



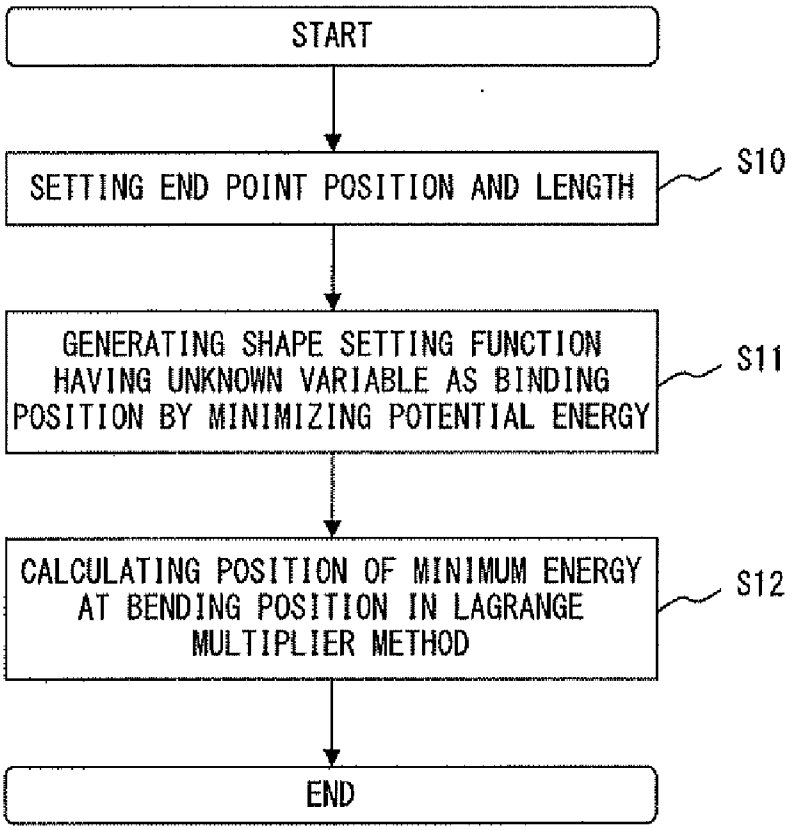

START
SETTING END POINT POSITION AND LENGTH
S10
GENERATING SHAPE SETTING FUNCTION HAVING UNKNOWN VARIABLE AS BINDING POSITION BY MINIMIZING POTENTIAL ENERGY
S11
CALCULATING POSITION OF MINIMUM ENERGY AT BENDING POSITION IN LAGRANGE MULTIPLIER METHOD
S12
END

FIG. 1

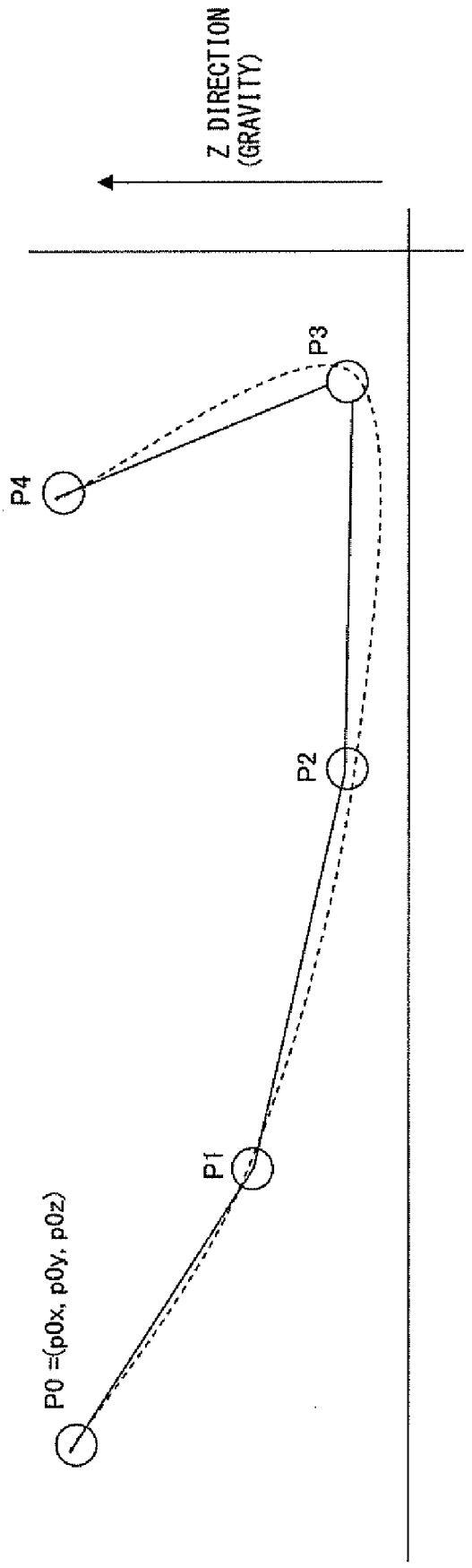


FIG. 2

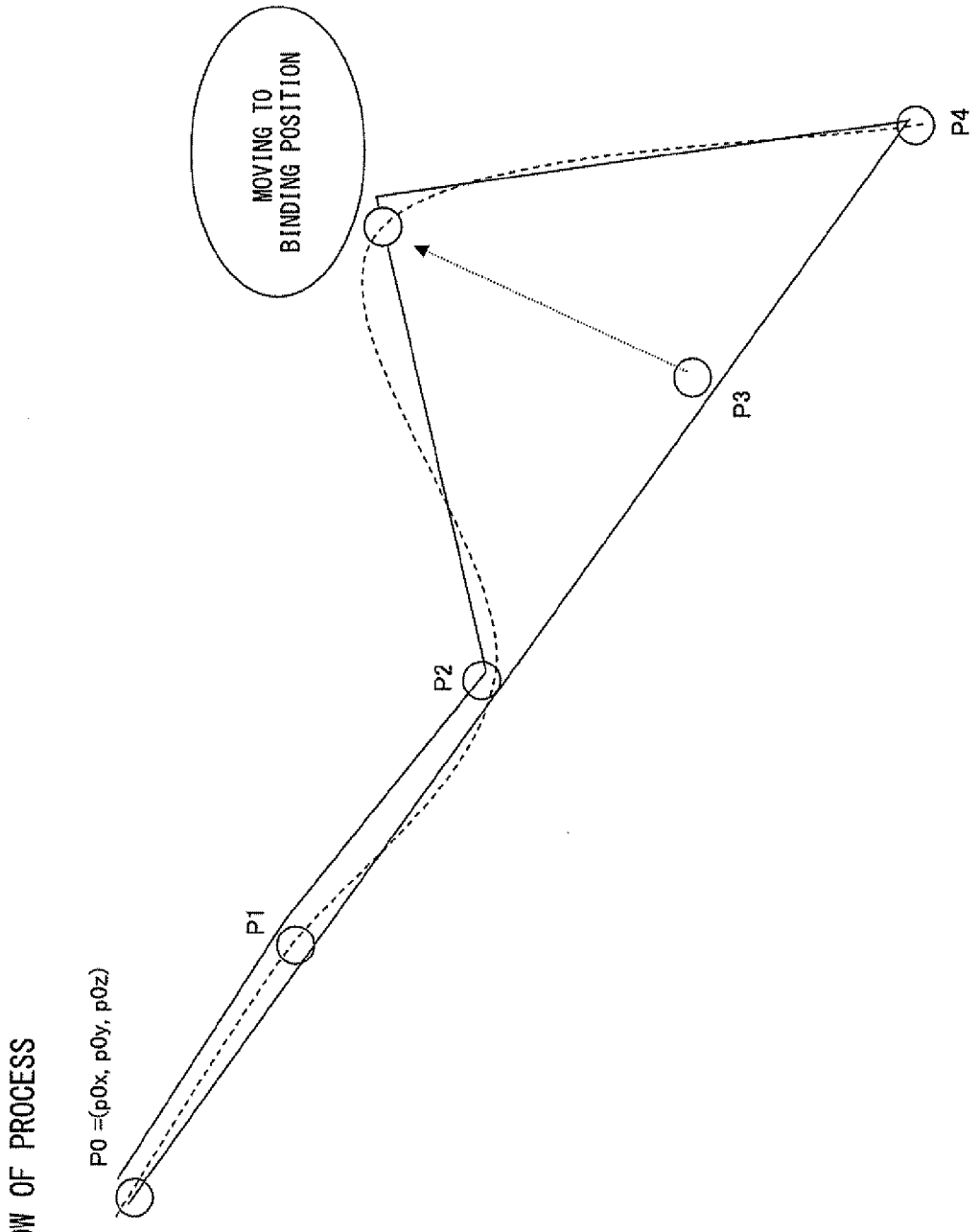

FLOW OF PROCESS
P0 =(p0x, p0y, p0z)
P1
P2
P3
P4
MOVING TO
BINDING POSITION

FIG. 3

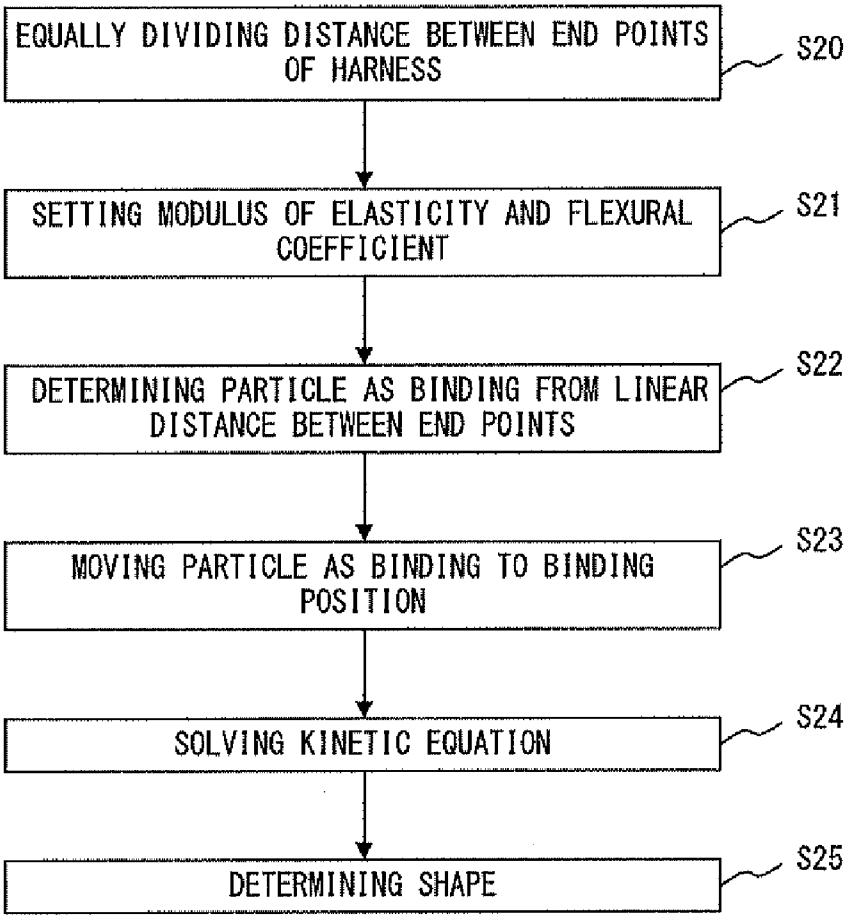

EQUALLY DIVIDING DISTANCE BETWEEN END POINTS OF HARNESS
S20
SETTING MODULUS OF ELASTICITY AND FLEXURAL COEFFICIENT
S21
DETERMINING PARTICLE AS BINDING FROM LINEAR DISTANCE BETWEEN END POINTS
S22
MOVING PARTICLE AS BINDING TO BINDING POSITION
S23
SOLVING KINETIC EQUATION
S24
DETERMINING SHAPE
S25

FIG. 4

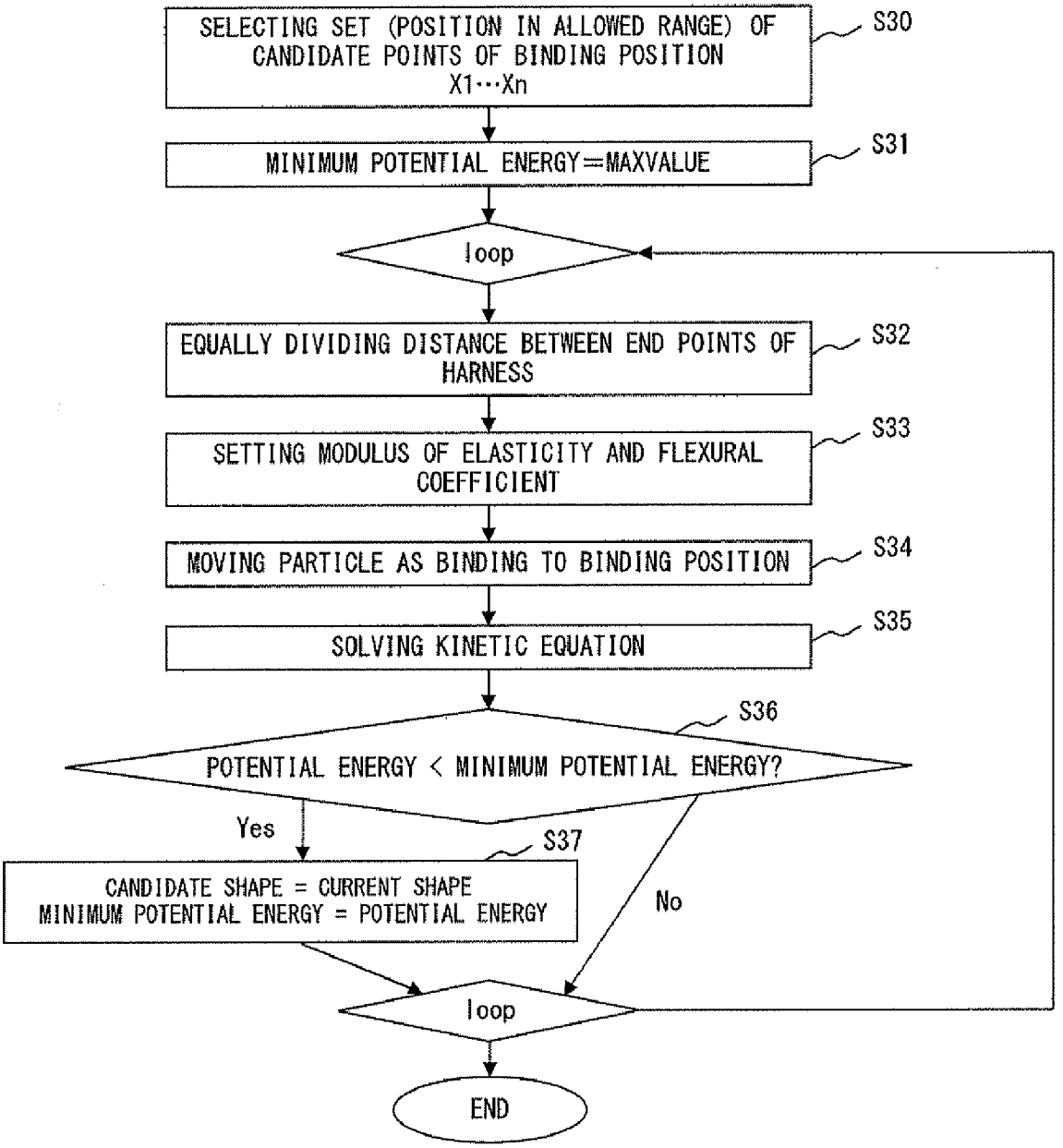

SELECTING SET (POSITION IN ALLOWED RANGE) OF CANDIDATE POINTS OF BINDING POSITION X1···Xn
S30
MINIMUM POTENTIAL ENERGY=MAXVALUE
S31
loop
EQUALLY DIVIDING DISTANCE BETWEEN END POINTS OF HARNESS
S32
SETTING MODULUS OF ELASTICITY AND FLEXURAL COEFFICIENT
S33
MOVING PARTICLE AS BINDING TO BINDING POSITION
S34
SOLVING KINETIC EQUATION
S35
S36
POTENTIAL ENERGY < MINIMUM POTENTIAL ENERGY?
Yes
No
S37
CANDIDATE SHAPE = CURRENT SHAPE
MINIMUM POTENTIAL ENERGY = POTENTIAL ENERGY
loop
END

FIG. 5

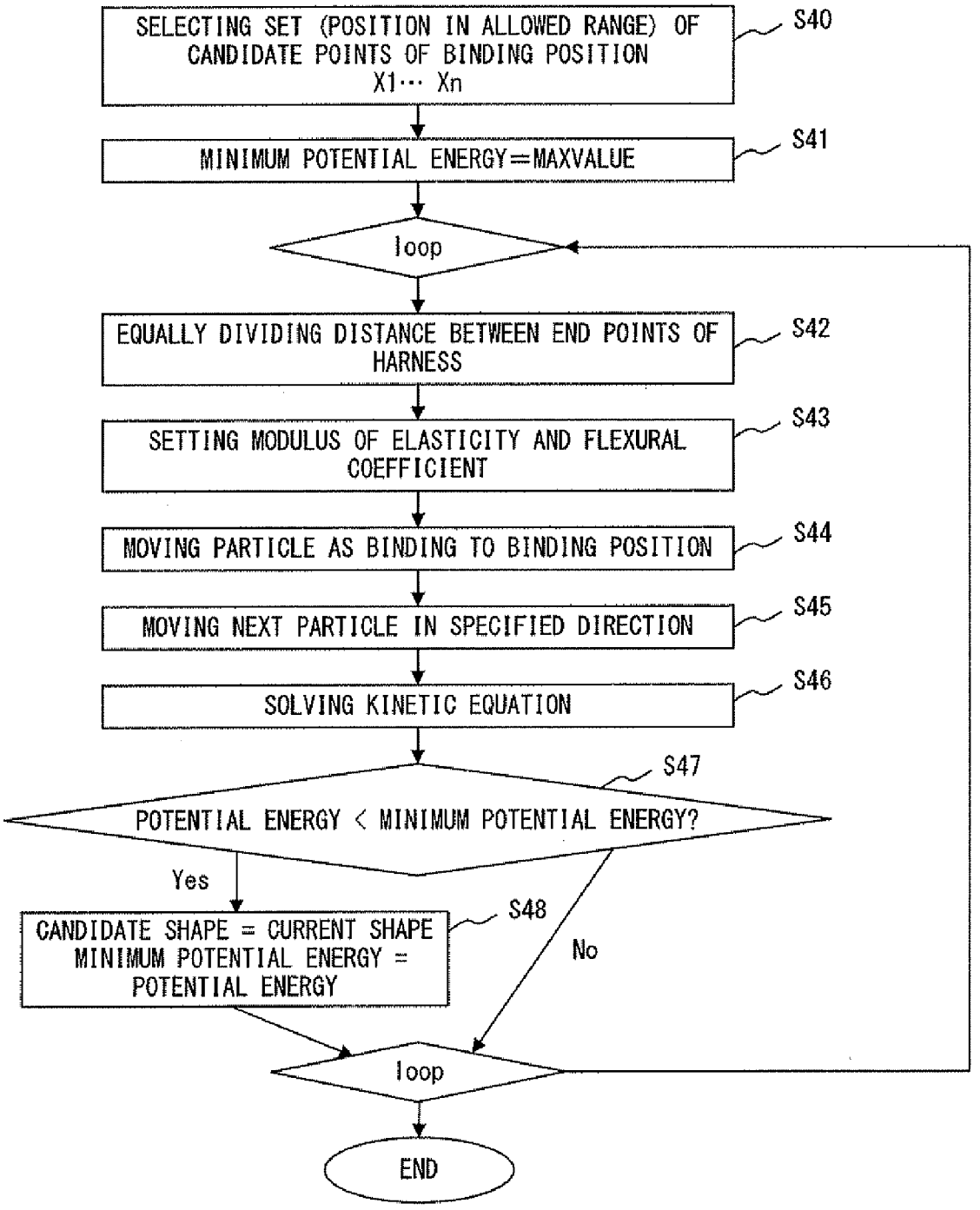

SELECTING SET (POSITION IN ALLOWED RANGE) OF CANDIDATE POINTS OF BINDING POSITION X1··· Xn
S40
MINIMUM POTENTIAL ENERGY=MAXVALUE
S41
loop
EQUALLY DIVIDING DISTANCE BETWEEN END POINTS OF HARNESS
S42
SETTING MODULUS OF ELASTICITY AND FLEXURAL COEFFICIENT
S43
MOVING PARTICLE AS BINDING TO BINDING POSITION
S44
MOVING NEXT PARTICLE IN SPECIFIED DIRECTION
S45
SOLVING KINETIC EQUATION
S46
S47
POTENTIAL ENERGY < MINIMUM POTENTIAL ENERGY?
Yes
No
CANDIDATE SHAPE = CURRENT SHAPE MINIMUM POTENTIAL ENERGY = POTENTIAL ENERGY
S48
loop
END

FIG. 6

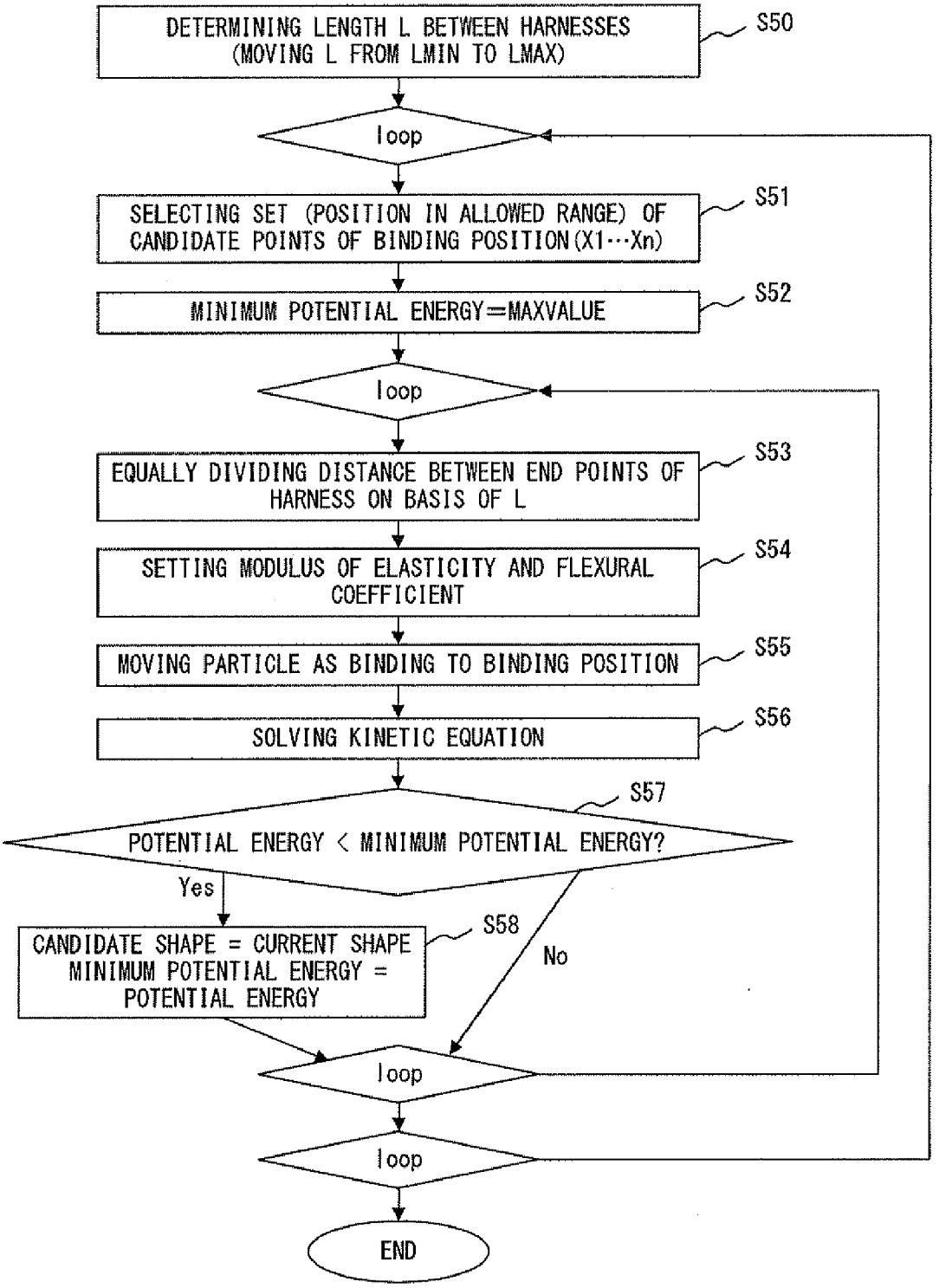

DETERMINING LENGTH L BETWEEN HARNESSES (MOVING L FROM LMIN TO LMAX)
S50
loop
SELECTING SET (POSITION IN ALLOWED RANGE) OF CANDIDATE POINTS OF BINDING POSITION (X1···Xn)
S51
MINIMUM POTENTIAL ENERGY=MAXVALUE
S52
loop
EQUALLY DIVIDING DISTANCE BETWEEN END POINTS OF HARNESS ON BASIS OF L
S53
SETTING MODULUS OF ELASTICITY AND FLEXURAL COEFFICIENT
S54
MOVING PARTICLE AS BINDING TO BINDING POSITION
S55
SOLVING KINETIC EQUATION
S56
S57
POTENTIAL ENERGY < MINIMUM POTENTIAL ENERGY?
Yes
No
CANDIDATE SHAPE = CURRENT SHAPE MINIMUM POTENTIAL ENERGY = POTENTIAL ENERGY
S58
loop
loop
END

FIG. 7

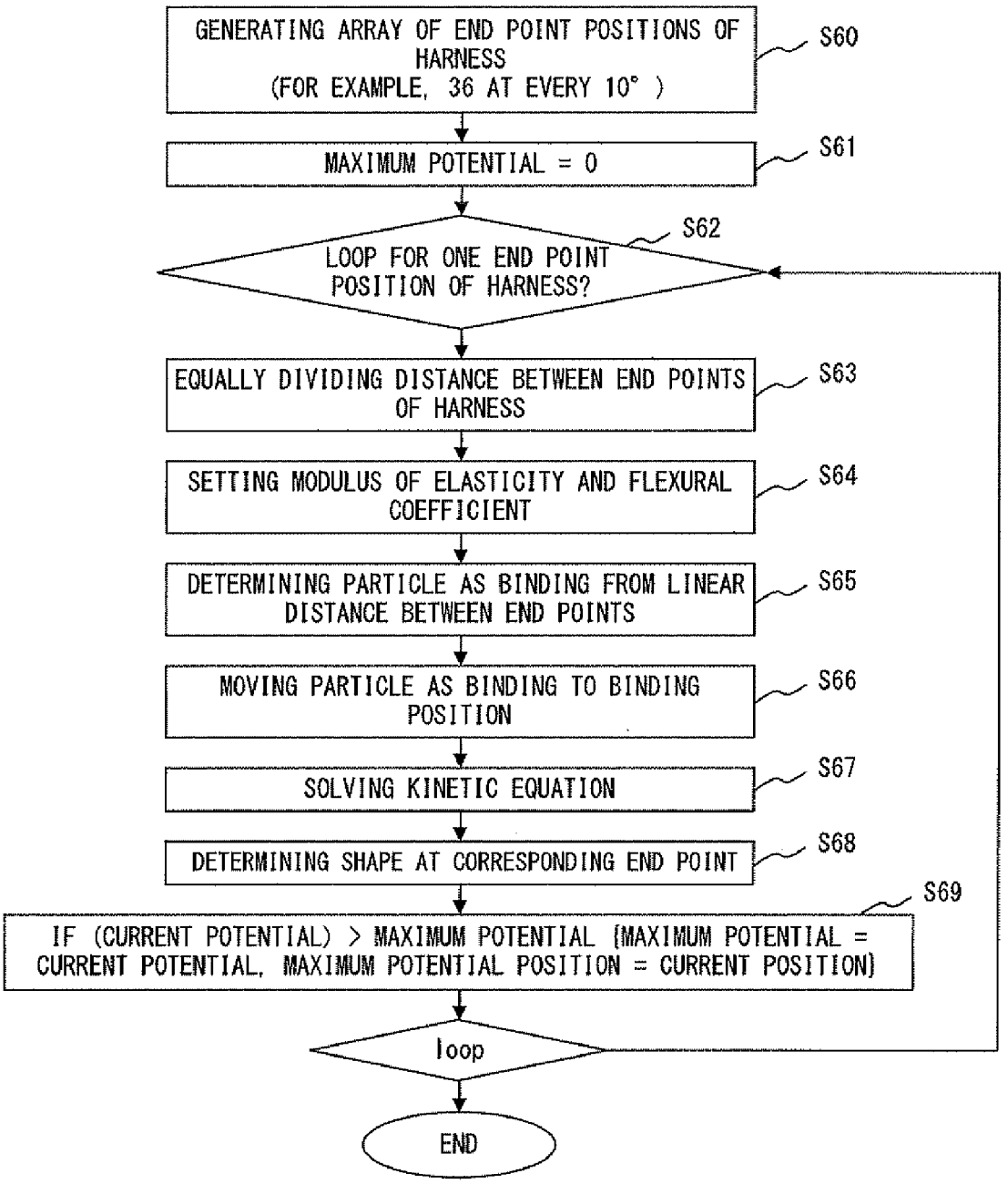

GENERATING ARRAY OF END POINT POSITIONS OF HARNESS (FOR EXAMPLE, 36 AT EVERY 10°)
S60
MAXIMUM POTENTIAL = 0
S61
LOOP FOR ONE END POINT POSITION OF HARNESS?
S62
EQUALLY DIVIDING DISTANCE BETWEEN END POINTS OF HARNESS
S63
SETTING MODULUS OF ELASTICITY AND FLEXURAL COEFFICIENT
S64
DETERMINING PARTICLE AS BINDING FROM LINEAR DISTANCE BETWEEN END POINTS
S65
MOVING PARTICLE AS BINDING TO BINDING POSITION
S66
SOLVING KINETIC EQUATION
S67
DETERMINING SHAPE AT CORRESPONDING END POINT
S68
IF (CURRENT POTENTIAL) > MAXIMUM POTENTIAL {MAXIMUM POTENTIAL = CURRENT POTENTIAL, MAXIMUM POTENTIAL POSITION = CURRENT POSITION}
S69
loop
END

FIG. 8

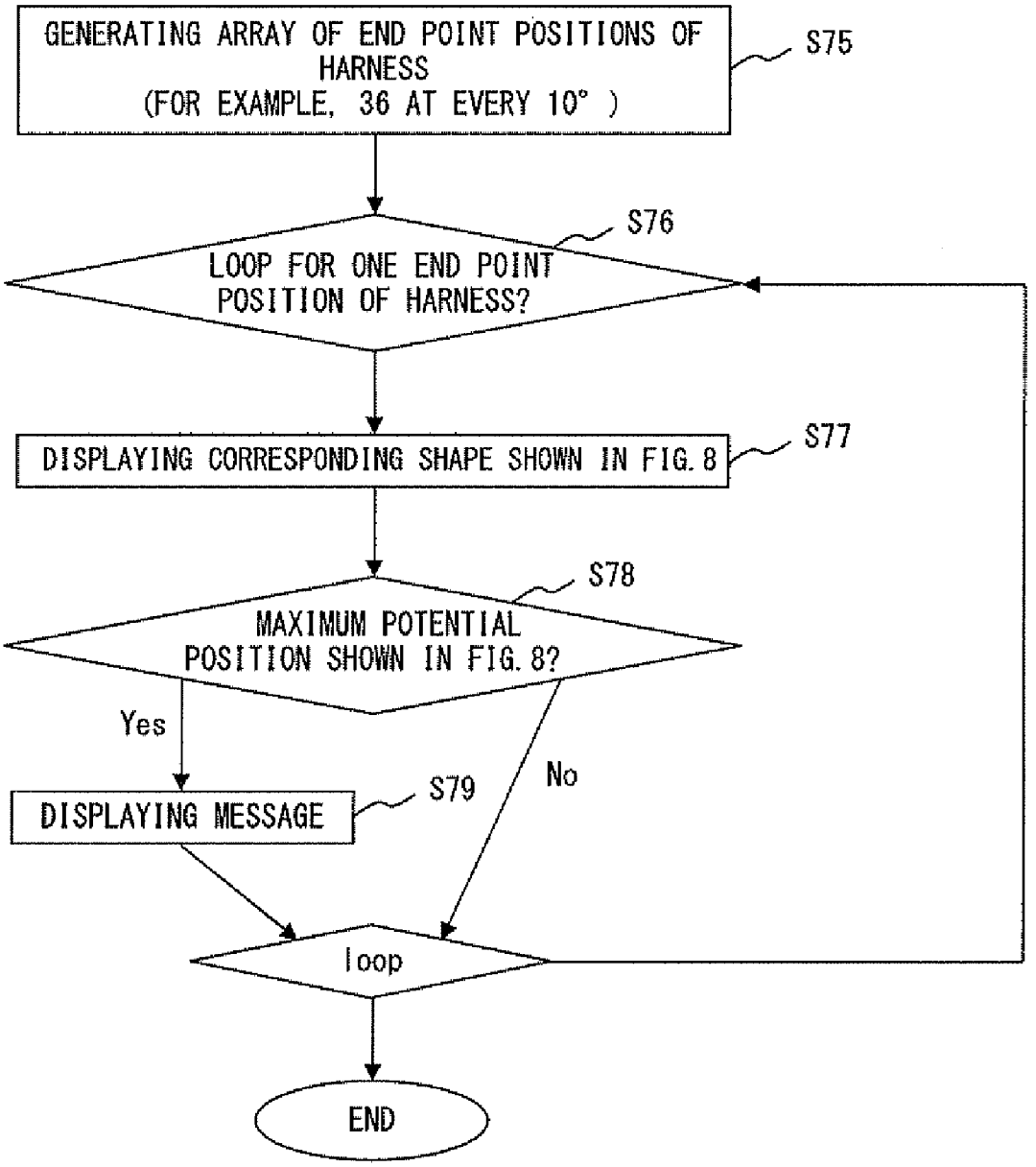

GENERATING ARRAY OF END POINT POSITIONS OF HARNESS
(FOR EXAMPLE, 36 AT EVERY 10°)
S75
LOOP FOR ONE END POINT POSITION OF HARNESS?
S76
DISPLAYING CORRESPONDING SHAPE SHOWN IN FIG. 8
S77
MAXIMUM POTENTIAL POSITION SHOWN IN FIG. 8?
S78
Yes
No
DISPLAYING MESSAGE
S79
loop
END

FIG. 9

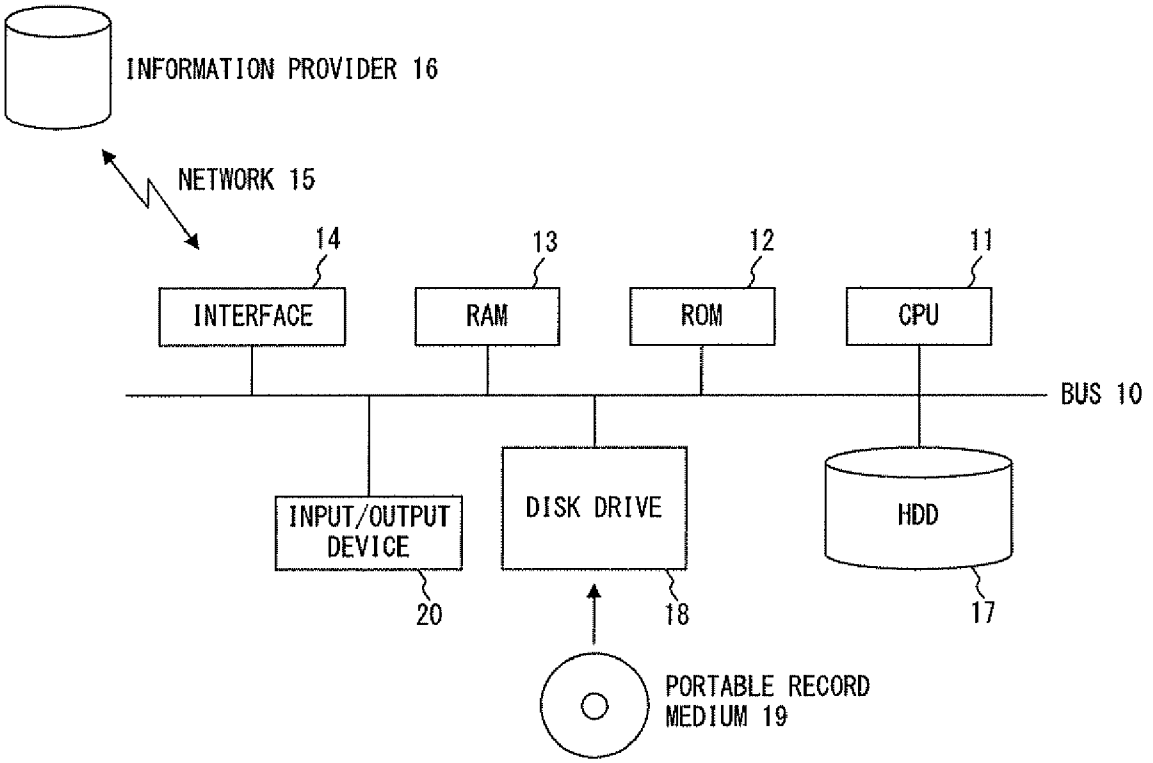

INFORMATION PROVIDER 16
NETWORK 15
14
13
12
11
INTERFACE
RAM
ROM
CPU
BUS 10
INPUT/OUTPUT DEVICE
DISK DRIVE
HDD
20
18
17
PORTABLE RECORD MEDIUM 19

FIG. 10

HARNESS DESIGN APPARATUS

BACKGROUND OF THE INVENTION

[0001] 1. Field of the Invention

[0002] The present invention relates to a harness design apparatus for automatically designing the arrangement of a harness etc.

[0003] 2. Description of the Related Art

[0004] In developing a mechanical product and a device, determining a wiring path of a linear flexible object such as a wire, a harness, a cable, etc. is referred to as harness designing. In the harness designing, the path, the fixed position, and the length of a harness is determined with the curvature, the length, the easier assembly, the interference and nipping when the mechanism moves, etc. taken into account. With respect to the harness designing, there is a harness design support system for virtually designing the shape of the harness on the digital mockup on a computer, and designing the path and the length of a harness.

[0005] A conventional technique of a harness design support system is recited in the nonpatent document 1 that discloses a method of calculating the shape of a harness to minimize the mechanical energy of the entire harness. However, it is a method of calculating the shape of a harness with the length of the harness and the positions of its both ends defined as restriction conditions, but does not describe a case where a harness is bound.

[0006] Conventionally, a user empirically and manually designs the binding position of each harness and the position of a device on which a binding portion is fixed, but there has been no technology of automatically performing the designing.

[0007] That is, in the conventional technology, each designer models a harness while considering the binding position and the fixing position, verifies the length and the curvature of the harness, and re-models a harness if there is a problem as a result of the verification, thereby designing the optimum arrangement by trial and error. Therefore, there has been the problem of dependency on the skill of a designer.

[0008] [Non-patent Document 1] Study report of Information Processing Society of Japan "Graphics and CAD" No. 113 IPSJ SIG Technical Report 2003-CG-113 "3-dimensional Design Support System" by Masayoshi Hashima, Yosuke Senda, and Yuichi Sato of Fujitsu Institute

[0009] It is necessary to determine in advance one or more binding positions of a harness (hereinafter referred to as "binding"). Thus, demanded is a method of correctly and efficiently determining the optimum binding position of a harness subject to the lightest load without depending on the skill of a designer.

SUMMARY OF THE INVENTION

[0010] The present invention aims at providing a harness design apparatus capable of automatically designing the optimum position at which a harness is bound.

[0011] The harness design apparatus according to an aspect of the present invention automatically designs a method of loading a harness. The apparatus includes: a condition setting device for acquiring a binding position on the harness or a restriction condition to be satisfied by the harness; and a binding position acquisition device for varying the binding position under the condition of the binding position indicated by the acquisition device, and acquiring as the binding position a position for minimal mechanical energy of the entire harness.

[0012] The optimum binding position for the lightest load on the harness can be automatically designed by obtaining a method of loading a harness for minimal mechanical energy on the entire harness under the restriction condition relating to the harness itself or the binding position.

[0013] The present invention can provide the harness design apparatus for automatically optimizing the binding position of a harness.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] FIG. **1** is a flowchart of the outline of the process according to an embodiment of the present invention;

[0015] FIG. **2** is an explanatory view (1) of obtaining the binding position for minimizing the potential energy;

[0016] FIG. **3** is an explanatory view (2) of obtaining the binding position for minimizing the potential energy;

[0017] FIG. **4** is a flowchart of the process of obtaining the shape of a harness;

[0018] FIG. **5** is a flowchart of the process of obtaining the binding position when the binding position can be moved only in an allowed range;

[0019] FIG. **6** is a flowchart of the process of obtaining the binding position when there is the binding condition of moving the position of a binding point only in the direction along a groove;

[0020] FIG. **7** is a flowchart of the process of obtaining the optimum length of a harness by changing the length of each wire in a constant range with the binding position specified in advance;

[0021] FIG. **8** is a flowchart of the process of determining the binding position of a wire harness whose end points can be driven;

[0022] FIG. **9** is a flowchart of the process of issuing a warning to a user by displaying the shape of the harness subject to the heaviest load after the process of FIG. **8**; and

[0023] FIG. **10** shows an example of the hardware configuration of a computer when the 3-dimensional harness design apparatus at the embodiments of the present invention is realized using a program.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0024] In the embodiment of the present invention, the binding point having the smallest potential energy is calculated by a kinetic equation using a length of a harness, an end point position of a harness, etc. as a binding parameter.

1) Harness design method

[0025] The harness to be designed according to the present embodiment (a linear flexible object such as a wire, a harness, a cable, etc. is hereinafter referred to simply as a harness) is generated in the following method.

[0026] Assuming that a harness is a curve of line and its potential energy is a sum of the elasticity energy of bending and twisting, and the position energy by gravity, the potential energy U is expressed as follows.

$$U = \frac{1}{2}\int_0^L R_f \kappa^2 \, ds + \frac{1}{2}\int_0^L R_t \omega^2 \, ds + \int_0^L Dz \, ds \quad \text{[Math 1]}$$

[0027] where s indicates the distance from the end point along the harness curve, κ, ω, z indicate the curvature, twist ratio, and height respectively at the point from the distance s. R_f, R_t, and D are respectively a flexural rigidity coefficient, a twist rigidity coefficient, and a linear weight per unit length, and depend on the material properties of the harness. L indicates a length of a curve. The harness curve that minimizes the energy can be obtained by solving the optimization problem with constraints using the positions of the start point and end point and the direction of a harness and the length of the harness as geometric restriction conditions.

2) When a binding is generated, the above-mentioned potential energy is given by a sum of two sections one of which is a section between the start point of a harness and a binding position, and the other of which is a section between the binding position and the end point.

3) Furthermore, when the constraints of the direction of the binding are considered, the direction is added to the restriction condition of the potential energy.

4) The base function of the harness curve can be a Bezier curve representing a free curve. Therefore, the data output by solving the minimization problem of the above-mentioned U is the minimum value of the U and a parameter of the Bezier curve. Using an approximated curve, a parameter space of the optimizing calculation can be narrowed, and the computational complexity can be reduced.

[0028] A generated shape can be displayed on an appropriate 3-dimensional mock-up simulator, and the shape of a harness can be transformed in real time while moving parts by a mouse etc.

5) In the present embodiment, the binding position is based on the potential energy (mechanical energy) U, the length L**1** of the harness from the start point to the binding, and the length L**2** of the harness from the binding to the end point of the harness as the function of the binding position V as follows. (Since the flexural rigidity coefficient, the twist rigidity coefficient, and the linear weight per unit length are constants, they are omitted here.)

$$U=U(V)$$

$$L1=L(V)$$

$$L2=L(V)$$

[0029] For example, L**1**+L**2** are fixed, and the potential energy is to be minimized when the binding position V is moved. To attain this, the well known Lagrange Multiplier Method is used. That is, using an undefined multiplier λ, the extremum problem of Y is to be solved by the following equation.

$$Y=U(V)-X(L1(V)+L2(V))$$

6) When the above-mentioned extremum problem is calculated,

[0030] V is obtained by the partial differentiation of Y made 0. It is obtained in the Newton-Raphson method in which an iterative approximation is performed by specifying an appropriate initial value. In the Newton-Raphson method, although the range of the V is restricted, the calculation is aborted when the V exceeds the specified range in the iterative calculation. Otherwise, the calculating method can be changed by amending the difference value from the calculation value.

7) When the curvature of the binding point is to be minimized, the curvature of the binding position is obtained from the output parameter of the Bezier curve described in 4) above.

$$C=C(V)$$

[0031] By the equation, the extremum problem can be solved as in the method described above.

8) To obtain the length with the binding position specified in advance, the binding position V is fixed, and the Lisa target value. Therefore, the following relational expression holds.

$$U=U(L,V) \text{ (V is fixed)}$$

[0032] On the other hand, as in 5) and 6) above, the extremum problem can be solved and the optimum value of L can be obtained. This method can be similarly applied as described in 7) above when the target of the extremum is a curvature.

9) When the end point of the wire harness can be driven, the following equations hold.

$$U=U(V,P1,P2)$$

$$L1=L(V,P1,P2)$$

$$L2=L(V,P1,P2)$$

[0033] where P**1** and P**2** indicate the positions of the end points. By general equations of mechanism, P**1** and P**2** are represented by the following equations using 0 as a joint value.

$Pi=F(\theta)+r$ (i=1 or 2) when driving is performed by a rotation joint

$Pi=L(\theta)+r$ (i=1 or 2) when driving is performed by a translation joint

[0034] where F indicates a polynomial by a trigonometric function, and L indicates a first-order equation of θ. Therefore, a partial derivative can be easily calculated in either equation. The result is substituted for the U to calculate the total differential.

[0035] This method can be similarly applied as described in 7) above when the target of the extremum is a curvature.

[0036] A joint normally varies only within a predetermined range. Then, the joint value in the range is calculated in advance on an appropriate scale, and the value of U is obtained, thereby successfully showing a warning to a user when the potential energy reaches the maximum value during operation by the 3-dimensional mock-up simulator.

[0037] FIG. **1** is a flowchart showing the outline of the process according to an embodiment of the present invention.

[0038] First, in step S**10**, the position of the end point and the length of the wire etc. to be bound by the harness are set. In step S**11**, a shape setting function in which a binding position is unknown variable is generated to minimize the potential energy. In step S**12**, using the shape setting function generated in step S**11**, the position of the minimum energy in the folded position is calculated in the Lagrange Multiplier Method.

[0039] FIGS. **2** and **3** are explanatory views of obtaining the binding position to minimize the potential energy.

[0040] In FIGS. **2** and **3**, the harness is divided into four divisions to obtain potential energy.

[0041] First, the following elements are determined in advance.

[0042] natural length between particles=1

[0043] modulus of elasticity between particles=K

[0044] modulus of flexural elasticity=R

[0045] mass of segment between particles=M

$$\text{potential energy}=0.5*\Sigma K*(|Pi+1-Pi|-1)^2+0.5*\Sigma R*(\text{square of the angle at } Pi)+0.5*\Sigma M*(Piz+P(i+1)z)$$

[0046] where Pi indicates the position of the i-th point on the harness.

[0047] To obtain the minimum value of the potential energy above, a differentiated kinetic equation is solved.

$$0=\Sigma K*(Pi+1-Pi-1)\Sigma R*(\text{angle at } Pi)+\Sigma M*(0,0,1)$$

[0048] It is a simple differential equation, and can be solved by a well known method (Runge-kutta).

cf. Numerical Recipes in C++: The Art of Scientific Computing Saul A. Teukoksky (author), William T. Vetterling (author), Brian P. Flannery (author), William H. Press

ISBN-10: 0521750334

[0049] pp713ff

[0050] Practically, as shown in FIG. **3**, a point on a harness is moved to a binding position, the above-mentioned kinetic equation is solved, and the shape of the harness is obtained at the binding position. The process is performed at various binding positions to obtain various binding positions and a binding position at which the minimum potential energy is provided is found from sets of each binding position and its shape of wire.

[0051] FIG. **4** is a flowchart of the process of obtaining the shape of a harness.

[0052] In step S**20**, the distance between the end points of a harness is divided into two equal parts. In step S**21**, a modulus of elasticity and a flexural coefficient are set. In step S**22**, a particle indicating a binding is determined from the linear distance between the end points of a harness. That is, the position forming the binding is determined on the basis of the ratio of the length from the start of a harness to the binding to the entire length of the harness. The particle on the harness forming the binding is moved to the binding position. In step S**24**, the above-mentioned kinetic equation is solved. In step S**25**, the shape of the harness is determined.

[0053] FIG. **5** is a flowchart of the process of obtaining the binding position when the binding position can move only within an allowed range.

[0054] First, in step S**30**, a set of candidate points of a binding position is selected in an allowed range. The selection is performed by a user. The binding position as an element of the set is set as X**1**, . . . , Xn. Then, in step S**31**, the initial value MAXVALUE is set as a variable (minimum potential energy). In step S**32**, the distance between the end points of the harness is equally divided into two parts. In step S**33**, a modulus of elasticity and a flexural coefficient are set. In step S**34**, a particle indicating a binding is moved to a position (one of X**1**, . . . , Xn) in the set of candidates for a binding position. In step S**35**, the kinetic equation is solved using the binding position. In step S**36**, it is determined whether or not the potential energy obtained by solving the kinetic equation is smaller than the variable (minimum potential energy). If the determination in step S**36** is NO, control is returned to step S**32**. If the determination in step S**36** is YES, then the current shape is set as the candidate shape for the harness in step S**37**, the current potential energy is set for the variable (minimum potential energy), and control is returned to step S**32**. The processes from step S**32** to step S**37** are performed on all points of the candidates for the binding position obtained in step S**30**, thereby terminating the process.

[0055] FIG. **6** is a flowchart of the process of obtaining the binding position when there is the binding condition of moving the position of a binding point only in the direction along a groove.

[0056] First, in step S**40**, a set of candidate points of a binding position is selected within a range satisfying the restriction conditions. The selection is performed by a user. In this case, for example, the restriction condition of a straight line along a groove etc. is to be satisfied. The binding position as an element of the set is X**1**, . . . , Xn. Next, in step S**41**, the initial value MAXVALUE is set as a variable (minimum potential energy). In step S**42**, the distance between the end points of the harness is equally divided into two parts. In step S**43**, the modulus of elasticity and the flexural coefficient are set. In step S**44**, a particle as a binding is moved to one position of the set (X**1**, . . . , Xn) of candidates for a binding position. In step S**45**, the particles on the harness other than the binding position are arranged after moved in a specified direction satisfying the binding condition. In step S**46**, the kinetic equation is solved. In step S**47**, it is determined whether or not the potential energy obtained by solving the kinetic equation is smaller than a variable (minimum potential energy). If the determination in step S**47** is NO, control is returned to step S**42**. If the determination in step S**47** is YES, then the current shape is set as a candidate shape for a harness in step S**48**, and the current potential energy is set as a variable (minimum potential energy), thereby returning control to step **42**. The processes from step S**42** to step S**48** are performed on all candidate points for the binding position obtained in step S**40**, thereby terminating the process.

[0057] FIG. **7** is a flowchart of the process of obtaining the optimum length of a harness by changing the length of each wire in a constant range with the binding position specified in advance.

[0058] First, in step S**50**, the minimum value lmin and the maximum value lmax of the problem of the harness are set, and the length l of the harness is selected between the minimum value lmin and the maximum value lmax. Next, in step S**51**, a user selects the set (X**1**, . . . , Xn) of the candidate points for a binding position. That is, a user determines in advance a binding position, and sets some binding positions to be calculated by a user as candidate points for a binding position. In step S**52**, the initial value of MAXVALUE is set as a variable (minimum potential energy). In step S**53**, the distance of the harness having the length of l is equally divided into two parts. In step S**54**, the modulus of elasticity and the flexural coefficient are set. In step S**55**, the particle as a binding is moved to the binding position. In step S**56**, a kinetic equation is solved on the basis of the set value. In step S**57**, it is determined whether or not the potential energy obtained by solving the kinetic equation is smaller than a variable (minimum potential energy). If the determination in step S**57** is NO, then control is returned to step S**53**, the kinetic equation is solved for different binding positions, and it is determined whether or not the potential energy obtained by solving the kinetic equation is smaller than a variable (minimum potential energy). If the determination in step S**57** is YES, then the candidate shape for a harness is set as the current shape of the harness in step S**58**, and the current potential energy is set as

a variable (minimum potential energy). The processes from step S53 to step S58 are repeated for the entire set of candidate points for a binding position. When the iterative process is completely performed on all candidate points for the binding position, control is returned to step S51, and the processes from step S51 to step S58 are repeated on the different lengths 1 of the harness. The length l of the harness is moved between the minimum value lmin and the maximum value lmax, and the optimum length and the shape of the harness and the minimum potential are obtained. The length l of the harness is between the minimum value lmin and the maximum value lmax, and a discrete value changing in a predetermined step is obtained. Thus, by changing a predetermined step, the length l of the harness calculated can be increased and decreased. When all cases of the length l of the harness are calculated, the process is terminated.

[0059] FIG. **8** is a flowchart of the process of determining the binding position of a wire harness whose end points can be driven.

[0060] Assumed here is, for example, the case in which one end of a wire harness is connected to a board provided with a keyboard in a notebook PC, and the other end is connected to the board of a monitor. In this case, by closing and opening the monitor, the position of the endpoint of the harness is rotated and changed. Thus, when the end point of the harness is rotated and moved, the optimum shape of the harness and position of the binding are obtained.

[0061] In step S60, the array of end points of the harness is generated. For example, 36 positions can be set every 10° from 0°. In step S61, the maximum potential is set to 0. The process in step S62 is a loop from step S63 to step S69 to be performed on all end point positions set in step S60. When one end point position is fixed, the distance between the end points of the harness is equally divided into two parts in step S63. In step S64, the modulus of elasticity and the flexural coefficient are set. In step S65, when the binding position is given by a ratio to the total length of the harness, the position of the particle as a binding is determined by the ratio of the linear distance between the end points. In step S66, the particle as a binding is moved to the binding position. In step S67, the kinetic equation is solved. In step S68, the shape of the harness at the end point position of the current process and the binding position are determined. In step S69, it is determined whether or not the potential energy obtained in step S67 is larger than the maximum potential energy. If the current potential energy is larger, the current potential energy is set to the maximum potential energy and the current position is set to the variable (maximum potential position). In step S69, when the current potential energy is equal to or lower than the maximum potential energy, no process is performed. After step S69, control is returned to step S62, and the processes from step S63 to S69 are performed on all end point positions. When the process is completed on all endpoint positions, the process is terminated.

[0062] In the processes shown in FIG. **8**, the potential energy obtained by solving the kinetic equation in step S67 is compared for all end point positions set in step S60, and the end point position is obtained when the heaviest load is applied (the maximum potential energy is marked).

[0063] FIG. **9** is a flowchart of the process of issuing a warning to a user by displaying the shape of the harness subject to the heaviest load after the process shown in FIG. **8**.

[0064] In step S75, the array of the end point positions of the harness (same as the array shown in FIG. **8** in which the array of 36 end point positions is generated at every 10° from 0°) is generated. In step S76, the process is a loop for repeating the processes from step S77 to step S79 on all end point positions generated in step S75. In step S77, the shape of the corresponding harness obtained in FIG. **8** is displayed on the screen of the computer for specific end point positions selected from the array of the end point positions generated in step S75. In step S78, it is determined whether or not the shape of the harness displayed in step S77 is the shape at the maximum potential position obtained in FIG. **8**. If the determination S in step S78 is NO, control is returned to step S77. If the determination in step S78 is YES, a message that the displayed shape of the harness refers to the maximum potential position is displayed on the screen of the computer in step S79, and control is returned to step S77. The loop from step S76 to step S79 continues until the process is completely performed on all end point positions included in the array of the end point positions in step S75. When the process is completed, it is terminated.

[0065] In the above-mentioned embodiments, the binding positions of a harness can be automatically and correctly determined although they have been conventionally determined manually by a designer when the harness is designed. It is also possible that the binding is determined only in a predetermined range due to the relationship with other parts when mechanical design is performed. Also in this case, as shown in FIG. **5**, the binding position of a harness can be automatically and correctly determined. Depending on the type of harness, the position from the start of the binding position is fixed. Similarly, as shown in FIG. **5**, the binding positions of a harness can be automatically and correctly determined. In addition, the fixtures used at the binding positions can limit the direction of the binding. In this case, similarly as shown in FIG. **6**, the binding positions of a harness can be automatically and correctly determined.

[0066] In addition, it is necessary to check in advance how long a harness can reduce the load. In FIG. **7**, a designer can automatically and correctly determine the length of a harness, which has been determined manually by a designer during designing the harness.

[0067] Furthermore, when the end point of a harness is fixed to a joint, the optimum binding positions of the harness naturally vary depending on the joint value of the joint. As shown in FIG. **9**, on the basis of the state in which the heaviest load is assumed in the drive range of the joint, the optimum binding position can be automatically and correctly determined. In this case, it is important from the viewpoint of securing the robustness in design to confirm the state in which the heaviest load is assumed. With reference to FIG. **9**, it can be easily realized.

[0068] FIG. **10** shows an example of the hardware configuration of a computer when the 3-dimensional harness design apparatus according to the embodiments of the present invention is realized using a program.

[0069] The program is stored in a hard disk **17**, read to RAM **13**, and executed by a CPU **11**. These components are interconnected via a bus **10**. ROM **12** stores a basic program such as a BIOS etc. the input from a user or the output to the user is performed by an input/output device **20**. The input/output device **20** includes an input device such as a keyboard, a mouse, etc., and an output device such as a display screen, a printer, etc.

[0070] When the program is stored in a portable record medium **19** such as a CD-ROM, CD-R, DVD, a diskette, etc., it is read from a disk drive **18**, and developed into the RAM **13** etc.

[0071] An interface **14** accesses a database etc. of an information provider **16** over a network **15**. The program can be accessed in the database of the information provider **16** and executed in a network environment.

What is claimed is:

1. A harness design apparatus which automatically designs a method of loading a harness, comprising:

a condition setting device acquiring a binding position on the harness or a restriction condition to be satisfied by the harness; and

a binding position acquisition device varying the binding position under a condition of the binding position indicated by an acquisition device, and acquiring as the binding position a position for minimal mechanical energy of the entire harness.

2. The apparatus according to claim **1**, wherein the restriction condition is provided as a ratio of a length from an end point of the harness to a binding to a total length of the harness.

3. The apparatus according to claim **1**, wherein

the restriction condition is to restrict a position of a binding of a harness within a predetermined range.

4. The apparatus according to claim **1**, wherein

the restriction condition is to allow a movement of a position of a binding of a harness only in a predetermined direction.

5. The apparatus according to claim **1**, wherein

the restriction condition is to vary a length of a harness in a predetermined range in a state in which a position of a binding is specified.

6. The apparatus according to claim **1**, wherein

the restriction condition is to move an end point of a harness in a direction in which the harness is bent.

7. The apparatus according to claim **6**, further comprising

a display device displaying to a user how the harness having a position of the endpoint at which the harness is subject to a heaviest load when the end point of the harness is moved, is mounted.

8. The apparatus according to claim **1**, wherein

the mechanical energy is given by a following equation with a modulus of elasticity between particles=K, a flexural rigidity coefficient=R, a mass of a segment between particles M and a Pi as a position of a particle on the harness.

$$\text{mechanical energy}=0.5*\Sigma K*(|Pi+1-Pi|-1)^2+0.5*\Sigma R*(\text{square of the angle at } Pi)+0.5*\Sigma M*(Piz+P(i+1)z)$$

9. The apparatus according to claim **8**, wherein

a shape of the harness that minimizes the mechanical energy is obtained by solving a following differentiation equation for Pi.

$$0=\Sigma K*(Pi+1-Pi-1)+\Sigma R*(\text{angle at } Pi)+\Sigma M*(0,0,1)$$

10. A computer-readable recording medium recording a program for allowing a computer to realize a harness designing method for automatically designing how to load a harness, the recording medium used to direct the computer to function as:

a condition setting device acquiring a binding position on the harness or a restriction condition to be satisfied by the harness; and

a binding position acquisition device varying the binding position under a condition of the binding position indicated by an acquisition device, and acquiring as the binding position a position for minimal mechanical energy of the entire harness.

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